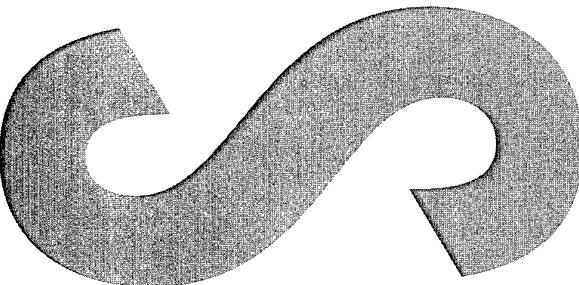
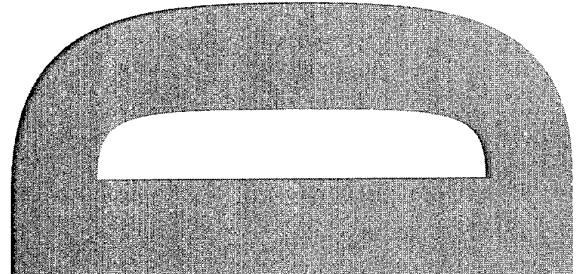


## **AMRL Evaluation of the JP-8+100 Jet Fuel Thermal Stability Additive**



Paul Rawson



DSTO-TR-1135

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# AMRL Evaluation of the JP-8+100 Jet Fuel Thermal Stability Additive

*Paul Rawson*

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Aeronautical and Maritime Research Laboratory

DSTO-TR-1135

## ABSTRACT

An additive package designed to improve thermal stability of jet fuel by 100°F (~38°C), known as the '+100 additive' or more commonly as the USAF-developed JP8+100 thermal stability additive, was evaluated to investigate its efficacy in reduction of thermal deposits formed in aircraft fuel systems. The additive was claimed to reduce deposits generated on fuel-wetted metal surfaces by up to 90%. An AED-designed rig capable of quantitatively evaluating jet fuel thermal stability was used to investigate jet fuels produced by different Australian refineries with various fuel finishing processes. The additive's effect on deposit formation from these fuels was investigated over a range of temperatures and fuel flow conditions giving both total deposit formation data and profiles of carbon and sulphur deposition on heat stressed, fuel-wetted steel tubing. This fuel additive is to be introduced into RAAF aircraft fuel systems that may have substantial levels of existing thermal deposit. An important consideration was thus the additive's ability to clean dirty fuel-wetted surfaces and the possibility of 'clumps' of deposit being washed into the fuel system. Levels of filterable deposit washed from a pre-deposited test section were monitored and the deposit levels were found to fall below levels generated in non-additised fuel. The +100 additive was found to substantially reduce the levels of carbonaceous deposit formed on hot metal fuel-wetted surfaces and performed as claimed in its ability to clean pre-deposited fuel wetted metal surfaces.

## RELEASE LIMITATION

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## Executive Summary

Jet fuel is used as the primary heat sink in all modern aircraft. As jet fuel is subjected to high heat loads, it undergoes thermal stress and will degrade. This degradation will lead to the formation of solid deposits in the aircraft fuel system and specifically in fuel nozzles. Thermally generated deposits are detrimental to efficient operation of aircraft engines and may cause damage in the hot section due to distorted fuel spray patterns. An additive developed for the United States Air Force, that is claimed to reduce fuel thermal deposit by up to 90%, was evaluated in an AED thermal stability test rig. This additive, widely known as JP8+100, was trialled over a range of jet fuel types and thermal stressing conditions and was found to be effective in both reducing thermal deposition and cleaning deposits from pre-dirtied fuel tubing.

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## 1. Introduction

Advanced military aircraft use fuel as the primary heat sink for both airframe and oil cooling. As a direct consequence of this function the bulk fuel temperature is increased (1,2). Jet fuel temperature is also increased as the fuel is exposed to hot engine components just prior to combustion, these hot components include the fuel nozzle support assemblies and the fuel nozzles. Jet fuel, when it is subjected to thermal stress, will undergo degradation either primarily by autoxidation if the fuel temperature is below 300°C, or by pyrolytic degradation, if the fuel temperature exceeds 400°C (3). This fuel degradation will form solid deposits that may develop as either filterable insolubles or as solid varnish-like deposits on fuel system surfaces. These insoluble compounds will be carried through the fuel system to collect in fuel filters and may agglomerate to form solid deposits. The varnish-like materials will form on fuel wetted hot metal surfaces, such as heat exchangers or in fuel nozzle orifices. The deposition, also known as surface fouling, reduces heat exchanger efficiency and may cause altered fuel spray patterns from fuel nozzles. This can lead to combustor buckling and overtemperature in the first stage turbine blades due to poor combustor pattern factor (4). Fuel thermal deposits have been observed on components from TF30 and T56 engines including the fuel nozzles, fuel nozzle support assembly fuel passages and a TF30 main oil cooler.

Research by engine manufacturers into thermal stability has led to standard engine component design constraints such as limiting the bulk fuel temperature at the airframe / engine interface to between 80-120°C and limiting the bulk fuel temperature at the inlet to the fuel nozzles to 163°C, and the maximum wetted wall temperature in the fuel nozzles to 205°C (5,6). These limitations are set to ensure minimal fuel thermal degradation and thus minimal deposit formation in the fuel system and system components. These arbitrary limits, however, do not take into consideration the intrinsic variations in the thermal stability of current jet fuels.

Fuel chemical composition plays a significant role in the deposit-forming tendencies of aviation fuel, thus the refinery finishing process that the jet fuel is manufactured by has a significant influence on the thermal stability of the fuel. The main fuel finishing processes used by Australian refineries are hydrotreating, MEROX and caustic washing. Some refiners may elect to simply 'straight run' their jet fuel if they believe it to be of sufficient quality to meet all specification requirements. The differing fuel-finishing processes give differing fuel chemistries over which any fuel additive must operate effectively. Each batch of aviation fuel has a unique composition, thus the chemical reactions contributing to the deposit formation and degradation of one fuel will be different from those of all other fuels. Minor fuel constituents containing hetero-atoms such as sulphur and nitrogen have been identified as major contributors to deposit formation (7).

The thrust of fuel additives to improve thermal stability has therefore been directed toward reducing the physical manifestation of fuel instability, primarily fuel thermal deposits. A new additive commonly known as the '+100' thermal stability additive has been developed by the BetzDearborn Hyrdocarbon Process Group Inc, in conjunction with the Wright Patterson Air Force Base Laboratories. The '+100' fuel additive is a mixture of chemical additives which reduces deposit formation on fuel wetted metal surfaces, rather than directly affecting the fuel chemistry to improve the fuel's tolerance to thermal stress. The '+100' additive package was designed to be effective in cleaning fuel systems that have been exposed to standard JP8 (F-34) and that have pre-existing levels of thermal deposit. The additive package was designed to reduce fuel thermal deposit formation and to improve fuel thermal stability by 100°F (38°C) over current levels.

The purpose of the investigation described in this paper was to assess the capabilities of the '+100' additive package in its ability to reduce the formation of fuel thermal deposits in RAAF aircraft fuel systems. Fuels typical of each of the major finishing processes were tested to ascertain the effectiveness of the additive over a range of fuel chemistries. A second component of the investigation was to evaluate the additive's effect on pre-deposited fuel system components. As aircraft may have substantial levels of thermally deposited material in their fuel systems, an understanding of how the additive interacts while cleaning these systems is essential. The possibility exists that large fragments of deposit may be dislodged during the cleaning process and be caught in small clearance fuel system components, or if sufficient material is dislodged as large-sized particle chunks it may accumulate and block fuel filters. A further issue of concern was the possibility of uneven clean up of fuel nozzles that could accentuate the effect of fuel spray pattern distortions that could lead to combustor burn-through.

This work did not address the well-known problem associated with the additive disarming water coalescers. This problem is a major issue but falls outside the scope of this investigation.

## 1.1 Jet Fuel Additives

Any proposed fuel thermal stability additive must be compatible with the current fuel additive package in F-34 and with fuel coked engine components. Current F-34 specification fuels contain a variety of additives. These additives are designed to improve both fuel performance and safety in military aircraft fuel systems (6,8,9). These additives include:

### Antioxidants

These are added to improve fuel storage stability and inhibit formation of peroxides and hydroperoxides, that chemically attack sealants in aircraft fuel systems. The current additive in use is a hindered phenol, added to fuel up to 24 mg/l.

**Fuel System Icing Inhibitor (FSII)**

Military aircraft do not normally use fuel heaters. The FSII is added to prevent water in the fuel from freezing and forming ice crystals that can block fuel filters. The FSII used in F-34 is diethyleneglycol monomethylether (DiEGME) added at a concentration in the range 0.1-0.15%. DiEGME has the extra advantage of acting as a biocide, inhibiting growth of sulphate reducing bacteria and fungi.

**Static Dissipaters**

The generation of a static charge while handling aviation fuel is a potential hazard. Fuel has a low conductivity, so a static dissipater is added to increase the conductivity to between 200 and 600 pS/m. The additive used is DuPont Stadis 450 with typical concentrations between 0.5 to 2.0 mg/l.

**Corrosion Inhibitor / Lubricity Improver**

Corrosion inhibitors were originally designed to protect commercial pipelines, they have since found use as both corrosion inhibitors and as an effective lubricity improving additive in jet fuel. Currently they are added to F-34 in concentrations from 6 to 31.5 mg/l. These additives are designed to prevent wear in fuel pumps. They are typically long chain fatty acids like dilinoleic acid, or their derivatives.

**1.2 USAF JP8+100 Program**

In 1989, the U.S. Air Force initiated a research program to increase the thermal stability of JP8. The development and requirements of jet fuels for military aircraft is the best compromise solution to engine performance requirements, fuel cost, and fuel availability. The main goal of the program was to increase the heatsink capacity of current JP8 fuel by 50% (a 38°C increase in fuel operating temperature) from 163°C to 201°C by developing additives to blend with the fuel at a cost of \$1 (\$US) per 1000 (US) gallons (6,8).

The stated major research tasks of the U.S. Air Force JP8+100 program were:

1. Identify and develop new fuel thermal stability test techniques.
2. Advance fundamental understanding of fuel thermal stability.
3. Develop global chemistry models and a thermal stability scale.
4. Formulate effective thermal stability improving additive packages.
5. Demonstrate, in actual aircraft flight time and maintenance records, the performance and cost savings produced by the use of new JP8+100 fuel.

**1.3 The '+100' Betz additive'**

The +100 additive is essentially a mixture of four main active ingredients, plus a number of solvents. The additive supplied to DSTO for evaluation had the trade name SPEC-AID 8Q462. Only limited information was available on the formulation and chemical composition of the additive. The material safety data sheet listed hazardous

ingredients and the known composition and function of each component of the additive are listed in Table 1.

*Table 1. Composition of SPEC-AID 8Q462*

Additive/ Ingredient	Chemical	Function
Antioxidant	Butylated Hydroxy Toluene	Inhibit gum formation
Metal Deactivator	N,N'-disalicylidene-1,2-propanediamine	Complex with trace metals to reduce catalysis of thermal oxidation reaction
Dispersant	Trade secret	Reduce size of solid particles Keep solids in solution
Detergents	Trade secret	Remove solids from surfaces
Aromatic Solvent	Alkylbenzenes, hydroaromatics	Solvent
Solvent	Naphthalene	Solvent
Solvent	1,2,4-trimethylbenzene	Solvent

## 2. Experimental Investigation

A program of experimental work was conducted to examine the improvement in fuel thermal stability offered by the +100 additive. USAF claims of the +100 additive reducing fouling by approximately 90% (10), under extended duration thermal stability test conditions, were also investigated. The test program was designed to evaluate aviation fuels produced by different refinery finishing processes and from current batches supplied to RAAF bases. Fuels were evaluated over a range of fuel flows and thermal stressing conditions, including an investigation of possible upper bulk fuel temperature limits for the additive to remain effective.

Experiments to assess the cleaning capacity of the additive were included in the program and involved producing fuel deposits in a laboratory test specimen and monitoring the levels of material cleaned from the predeposited test section by additised fuel. The cleaning capacity was quantified by comparing deposition in test specimens both before and after exposure to additised fuel.

### 2.1 Sample Fuels

The fuel samples used in this work were four F-34 Fuels. Three of the fuels were obtained from RAAF Bases Pearce, Amberley and Townsville, with the fourth being

obtained from a refinery that produces hydrotreated fuel with F-34 specification additives. These fuels also corresponded to the three major jet fuel finishing processes, namely straight run (RAAF Amberley), MEROX (RAAF Pearce) and hydrotreated fuel types. The fuel from Townsville was included as a known fuel of poor quality; it exhibited poor storage stability characteristics and is considered the most thermally unstable fuel ever delivered to RAAF. This fuel was responsible for filter blocking problems associated with its poor storage stability and the production of a black sediment in the bulk fuel. It has been labelled the "Black Fuel" in this report. All fuels were filtered through a glass fibre type GF/A 0.8 micron filter before testing.

## 2.2 Fuel Heat Stressing

All fuels evaluated in the trial were heat stressed in a Thermal Stability Rig (TSR) developed in the Airframes and Engines Division of DSTO. The TSR is essentially a single pass heat exchange system in which the fuel flows at low flow rates through small diameter stainless steel tubing. Each fuel was passed through an identical stainless steel tube test section 660mm long shaped into a U. The rig and tube test sections are constructed from 3.18 mm O.D. x 2.2mm I.D. annealed type 304 chromatography grade stainless steel tubing. Fuel flows from 0.1-9.9 ml/min are maintained by a Waters Model 510 HPLC pump. The pump is capable of developing and maintaining high system pressures, (up to 41 MPa), and is fitted with a surge suppressor to dampen the effect of pump piston pulsations. The system pressure is maintained at greater than 3.45 MPa via a NUPRO series R3A 2400-5150 kPa pressure release valve. Heating up to 600°C is provided by a Techne SBL-2 fluidised sand bath. All fuels were continuously air-sparged for the duration of the fuel heat stressing. This was done to ensure consistent levels of oxygen saturation of the test fuels with out the necessity of oxygen sparging.

The fuels were heat-stressed under three different temperature and fuel flow profiles, as listed in Table 2. The fuel low flow conditions for the 250-450°C tests were to study the fuels when subjected to near isothermal test conditions. Low fuel flow rates were considered desirable to increase fuel residence times in the hot zone of the test rig. The 350°C fuel thermal stressing conditions were designed as a test that could be completed in one day and would provide sufficient thermal deposits for quantification. All fuel-stressing temperatures were above the current 163°C maximum to accelerate thermal deposition rate and reduce test time to a manageable duration.

Table 2. TSR fuel heat-stressing conditions.

Test Temperature (°C)	Test Fuel Flow Rate (ml/min)	Test Duration (hours)	Fuel Volume (ml)
250	0.5	12	360
350	2	6	720
400	0.5	12	360

To determine the cleaning effect of the +100 additive on thermally-deposited fuel system components a TSR tube was prepared by heat stressing the RAAF Black Fuel for 30 hours at 350°C and at a flow rate of 2.0 ml/min. Then 100 ml aliquots of the Hydrotreated F-34 + 256 ppm of the +100 additive were run through the pre-deposited tube under the same test conditions. Each 100 ml of post stressed fuel was collected and the amount of deposits formed was determined gravimetrically. The rig has a lag time to reach the test temperature and this must be factored into the post run analysis when determining total amounts of deposit generated at each test temperature.

### **2.3 Thermal Deposit Determination (Analytical Methods)**

The post-test tubing is rinsed with hexane to remove residual fuel, dried in a vacuum oven at 100°C and cut into 3 cm long sections for deposit analysis. The sections are analysed with LECO CS-244 Carbon and Sulphur Analyser using either Lecocel-II or Lecocel-I plus tin combustion accelerators and standardised against high precision steel standards. This method combusts the test piece and measures total carbon and sulphur contents, thus requiring a blank of clean tubing to be subtracted from the test section values. This method assumes that all carbon and sulphur determined is acquired from the thermal deposits and relies on a single point calibration against high precision combined carbon and sulphur standards. The Leco equipment balance offers only three decimal place precision so to improve analytical precision a laboratory balance was used to measure the test section mass to four decimal places.

### **2.4 Cleaning Effect of Betz +100 additive**

Test tubing was prepared by heat-stressing the thermally unstable Black Fuel for 30 hours at 350°C at a flow rate of 2.0 ml/min. The insoluble material formed in the bulk fuel was filtered at the end of each 6-hour run interval giving an average of 3.6 mg/l of filterable insolubles formed over the 30 hour test. The pre-deposited tube was then washed with additised fuel. The fuel chosen for the tube cleaning studies was the relatively thermally stable Hydrotreated fuel (Figure 2) containing 256ppm additive under the same test conditions (ie. 350°C and 2.0 ml/min). Each 100 ml of the wash was collected and filtered though a 0.8 micron glass fibre filter to quantify the levels of filterable insoluble material washed from the test piece.

## **3. Experimental Results and Discussion**

### **3.1 Carbon Deposition Profiles 250°C and 350°C**

Total carbon analysis of the TSR test pieces sectioned into the 3 cm lengths gives both total carbonaceous deposit-forming characteristics of each test fuel, and a carbon deposition profile for each fuel over the length of the test section. These profiles are

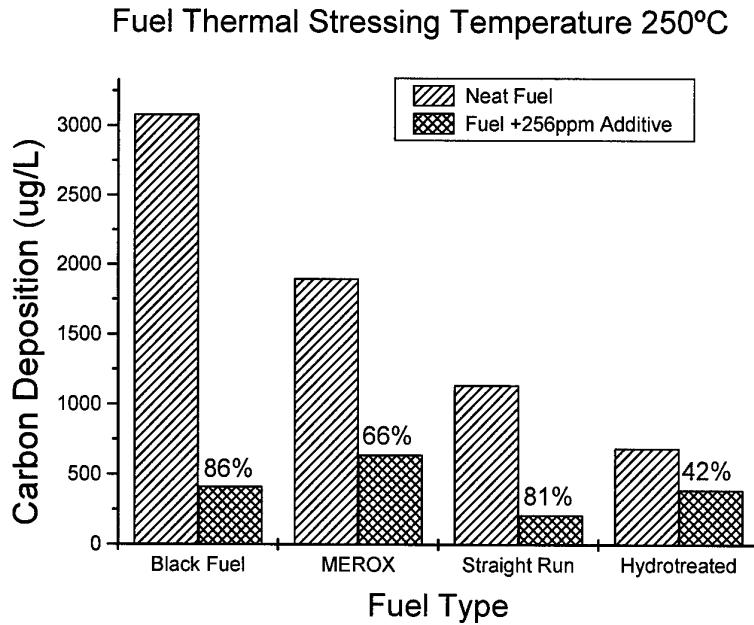
useful for determining the possible chemical mechanisms of deposit formation, and for studying the effect of the +100 additive on the fuels and on deposit formation. Profiles of total carbon deposition versus fuel type, both with and without the +100 additive were generated to determine the effectiveness of the additive in reducing the formation of thermal deposit in fuel lines under various temperature conditions.

Fuel thermal deposition is dominated by the autoxidation of compounds in the fuel. The +100 additive must be able to minimise deposition in fuels that exhibit all types of fuel chemistries and hydroperoxide-forming capacities. It is known (1) that hydroperoxides form in jet fuel above 205°C and are stable up to about 300°C. Above 300°C the hydroperoxides decompose into alcohols and ketones, further reacting to form deposit precursors. The effect of temperature on fuel fouling kinetics are very complex (1, 20). In order to assess the importance of fuel temperature in the formation of deposits, and the effectiveness of the Betz additive the 250°C, 350°C and 400°C stress temperatures were chosen.

The effect of the +100 additive on fuels of different refinery finishing processes can be seen in Figure 1. The fuel thermal stabilities without the additive follow the ranking from least to most thermally stable, Black Fuel < MEROX < Straight Run < Hydrotreated. The hydrotreated fuel was significantly more thermally stable at 250°C than the Black Fuel in the TSR, however both fuels passed the specification ASTM D3241 Thermal Oxidation Stability of Aviation Turbine Fuels by Jet Fuel Thermal Oxidation Tester (JFTOT) procedure, the Black Fuel passing the test repeatedly even after the discovery of its poor storage stability (11).

The +100 additive offered significant improvement in the fuel thermal stability as measured by the reduction in thermal deposition in the TSR under identical test conditions. The reductions are displayed as percentage indicators over the Fuel +Additive (256ppm) column displayed in Figure 1. The reduction in thermal deposition followed the trend from most improved to least improved: Black Fuel 86% > Straight Run 81% > MEROX 66% > Hydrotreated 42%. Thus, it can be seen that for even the most thermally stable Australian-produced jet fuel, the +100 additive offers a significant reduction in the levels of carbonaceous deposition.

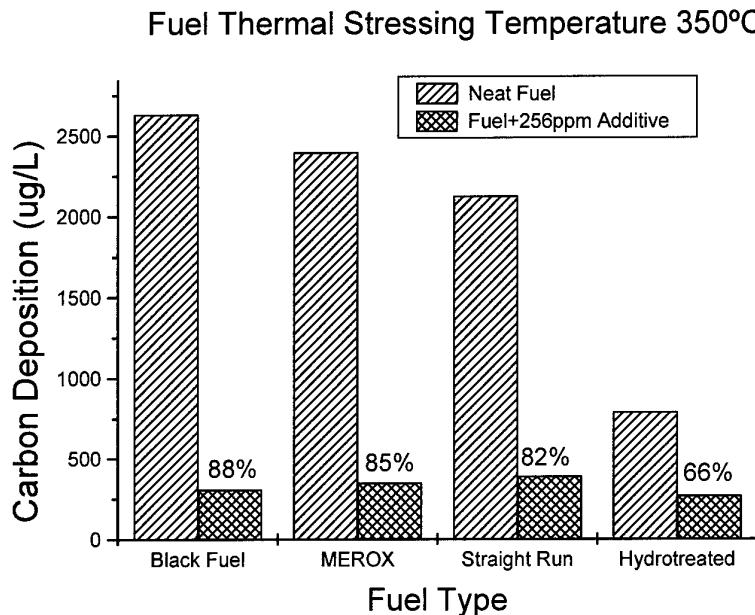
The ranking of thermal stability is changed for the additised fuels (Figure 1.), the new ranking from least to most thermally stable is MEROX < Black Fuel < Hydrotreated < Straight Run. The straight run additised fuel offers the highest thermal stability. This improvement may be due to the natural antioxidant compounds found in most straight run aviation fuels (7) which may be augmented by the +100 additive to increase the fuel's resistance to oxidation reactions, and thus increasing its thermal stability. These natural antioxidants are removed in the hydrotreatment fuel finishing process. The MEROX treated additised fuel has become the least thermally stable. This effect is due to the retention of thermally unstable disulphide compounds in the fuel (12,13) which are a byproduct of the MEROX treatment. In the case of the MEROX fuel the +100 additive is least effective in improving thermal stability.



*Figure 1. Fuel Thermal Stressing Temperature 250°C; reductions (%) in deposition from +100' additised fuels*

When the thermal stressing temperature is increased to 350°C (Figure 2.), the trend for thermal stability of the aviation fuel types remains the same as for the 250°C stress conditions, that is fuel thermal stability from least to most thermally stable fuel, Black Fuel < MEROX < Straight Run < Hydrotreated. The trend for reduction in thermal deposition changed from the 250°C test conditions with deposit reduction following the trend from most reduction to least, Straight Run 88% > Black Fuel 85% > MEROX 82% > Hydrotreated 66%. The rate of deposition has decreased in the neat Black Fuel, while it has increased for the other fuel types tested. This is possibly due to the change in fuel stressing temperature on the complex chemical reactions influencing deposit formation in each fuel type.

The trend for the additised fuel at 350°C shows the Black Fuel, MEROX, and straight run fuels as having similar thermal stabilities, with the hydrotreated fuel being the most thermally stable. The additised straight run fuel is less thermally stable at the higher test temperature possibly due to a higher rate of depletion of natural antioxidants. The straight run fuel still contains fuel components that may contribute to fuel thermal instability which will react at a higher rate to form deposits in the steel test tube. Other fuel components such as sulphur and nitrogen compounds, oxidation products or intermediates and trace contaminants such as metals may also influence the deposition rate in fuel.



*Figure 2. Fuel Thermal Stressing Temperature 350°C; reductions (%) in deposition from '+100' additised fuels*

### 3.2 Thermal Stability of +100 additive at 400°C

The additive was tested at 400°C, well above the proposed 201°C maximum expected to be experienced by the additised fuel in current generation aircraft. The 400°C stress temperature is well above maximum fuel temperature expected under normal operating conditions in current generation aircraft engines. The requirement to improve the thermal stability of aviation fuel for new generation gas turbine engines has already given rise to JP+225 and JP900 thermal stability improvement programs (14,15). The ability of the additive to improve fuel thermal stability at this high temperature was investigated (Figure 3.).

The test fuels exhibited the same thermal stability trend found for the 250°C and 350°C test conditions, however an increase in the amount of deposit generated was observed for all fuels additised with the +100 additive. This increase follows the trend of highest to lowest, Hydrotreated 161% > Straight Run 30% > MEROX 29% > Black Fuel 10%. The most thermally stable fuel at the lower test temperatures has been most degraded by the additive at 400°C and the least thermally stable Black Fuel has been least effected. The increases may be due components in the additive breaking down and contributing to the increase in thermal deposit formed in the test. These test results indicate that the +100 additive has a definite maximum temperature to which it can be

effective in reducing the formation of deposits in an aircraft fuel system. The dramatic increase in thermal deposition in the hydrotreated fuel demonstrates the significant contribution that small changes in the fuel chemistry can make to the overall thermal stability of the fuel. In this case, the introduction of the +100 additive at 256 ppm into the fuel has caused a 161% increase in the mass of thermal deposit formed in the normally thermally stable hydrotreated fuel.

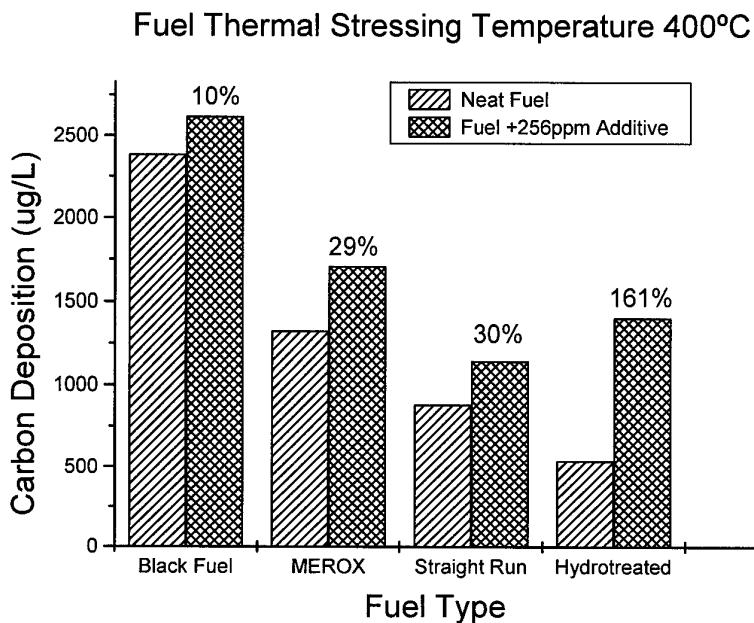


Figure 3. Fuel Thermal Stressing Temperature 400°C

### 3.3 Carbon Deposition Profiles

Each of the fuels evaluated in the trial had its thermal stability assessed quantitatively using an AED designed and constructed thermal stability rig described in detail in section 2.2. At the end of each test the 660 mm test piece was sectioned into 30 mm lengths for total carbon evaluation. These carbon results, plotted as in Figure 4, display a typical carbon deposition profile for each fuel, in the case of Figure 4, the MEROX treated fuel. These profiles provide information on total carbon deposition and comparative profiles both with and without the additive. A maximum deposition rate can be seen in the fourth and fifth tube sections for the neat and additised fuels respectively. This is common for all fuel types and would suggest a lag in maximum deposition rate occurring in the additised fuel. This lag is possibly due to the protective effect of the antioxidant component in the +100 additive, providing oxidative stability for the fuel until it or the available oxygen in the fuel is consumed.

The deposition profiles for 350°C show that over 97% of the total deposit formation occurs in the first half of the test tubing. This occurs due to the dependence of the formation of solid thermal deposits on the availability of oxygen to drive autooxidative chemical reactions that lead to deposit formation (16,17,18). The deposition profiles for the fuels stressed at 250°C (Figure 5) display an overall lower deposition rate for the neat fuel and a higher deposition rate for the additised fuel, when compared to the 350°C stressed fuel. These data suggest that differing rates of deposit formation will occur in sections of the aircraft fuel system that subject the fuel to different heat loads. The lowering of the fuel stressing temperature shifts the maximum deposition to the sixth tube section for the additised fuel and has not changed for the neat fuel. The +100 additive offers an extended induction period at lower temperatures. This result is important when the residence time of fuel in contact with hot metal surfaces in the aircraft fuel system is considered (14). The fuel can therefore be provided with a longer induction period before the formation of thermal deposits at cooler temperatures.

Deposition profiles for the fuels stressed at 250°C indicate a spike of deposit occurring in the 59-62 cm section of the test tubing. This increase may be due to the formation of compounds in the hot zone for which solubility in the bulk fuel is temperature dependent. The end section of the tube is cooler as the tube wall is at the fluidised sand bath-air interface, near the exit end. The fuel will cool at the very low laminar flow rate of 0.5 ml/min and the compounds' solubility in the cooler bulk fuel will decrease and in all likelihood drop out of solution and adhere to the tube metal surface (6,16). Not all of the fuels tested exhibited this behaviour, suggesting the phenomena is fuel chemistry dependent. This result may be significant as it suggests the possibility of thermal deposits occurring in normally unexpected aircraft fuel system components. Any region of the fuel system that experiences heating then immediate cooling may have an increased probability for thermal deposit formation. A preliminary study of this phenomenon has been conducted (21).

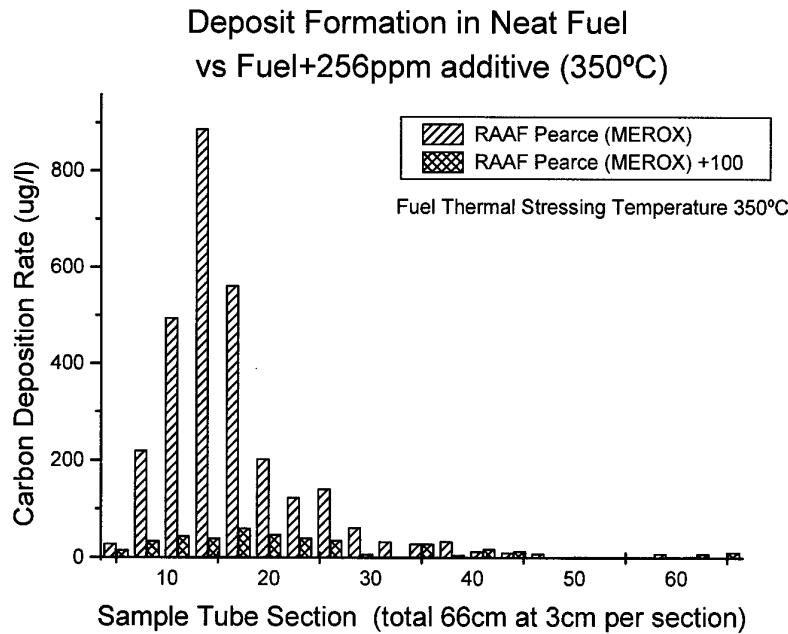


Figure 4. Comparison of Thermal Deposition in a neat fuel vs fuel + 256ppm additive (350°C)

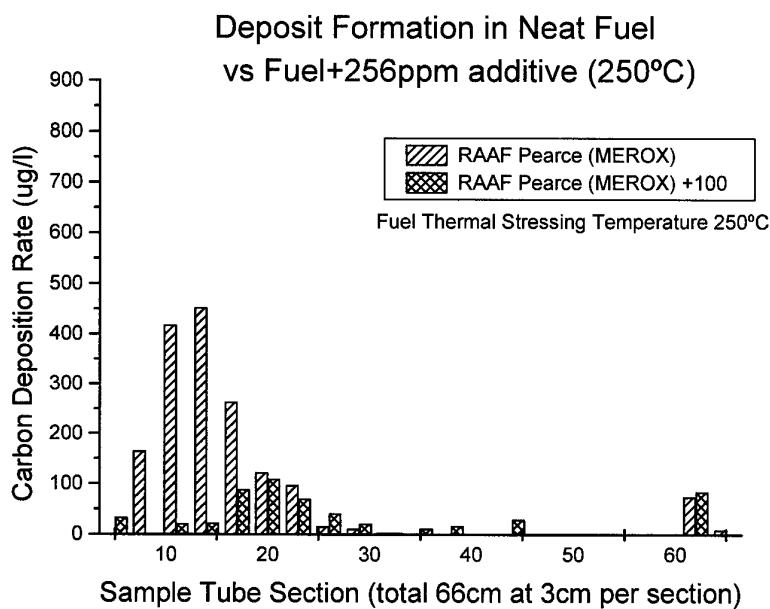


Figure 5. Comparison of Thermal Deposition in a neat fuel vs fuel + 256ppm additive (250°C)

### 3.4 Cleaning Effect of +100 Additive

Experiments were conducted to evaluate the potential of the +100 additive to clean pre-existing deposits from fuel system components. A pre-deposited test piece (steel tube) was washed with hot, additised fuel as described in Section 2.4, and the washing was collected in 100 ml aliquots. This fuel was filtered through a 0.8 micron glass fibre filter to quantify the levels of filterable insolubles washed from the tube (Figure 6.). The level of filterable insoluble material was never higher than 1.76 mg/l and the test was stopped after 700 ml of fuel had been washed through the tube.

A direct comparison of the fuel's deposition profiles is displayed in Figure 7. This Figure compares a pre-deposited tube's deposition profile against the tube that was washed with 700ml of Betz additised fuel. The additised fuel was able to clean over 90% of the thermal deposit from the pre-deposited test tube, cleaning out 11614 micrograms of deposit. This result indicates that the additised fuel has the capacity to clean 16591 micrograms of thermal deposit per litre of fuel.

A contribution to the final deposit level will be from the additised fuel itself. An additised, hydrotreated fuel can be expected to contribute approximately 230 micrograms of deposit under the fuel stressing conditioning for this test.

This large quantity (16591 micrograms) of deposit cleaned from the tube has not been caught on the 0.8 micron glass fibre filter, suggesting that the dispersant in the +100 additive has been effective in keeping the deposit washed from the tube surface in the bulk fuel solution. The dispersant also reduced the tendency of insoluble gums generated from forming large agglomerations of filterable insolubles. This effect is graphically displayed in the comparative photos of two filter papers (Figure 8.). The thermally stressed Black Fuel formed on average 3.8 mg/l of filterable insoluble material for each test while additised Black Fuel formed an average of only 1.4 mg/l of material.

The particle size of the deposits was not determined. However, other workers have determined the particle size distribution with a photo correlation technique as varying between 0.3 and 0.8 microns (19). Particles in this size range would not have any ill effects downstream of the combustion zone in an aircraft.

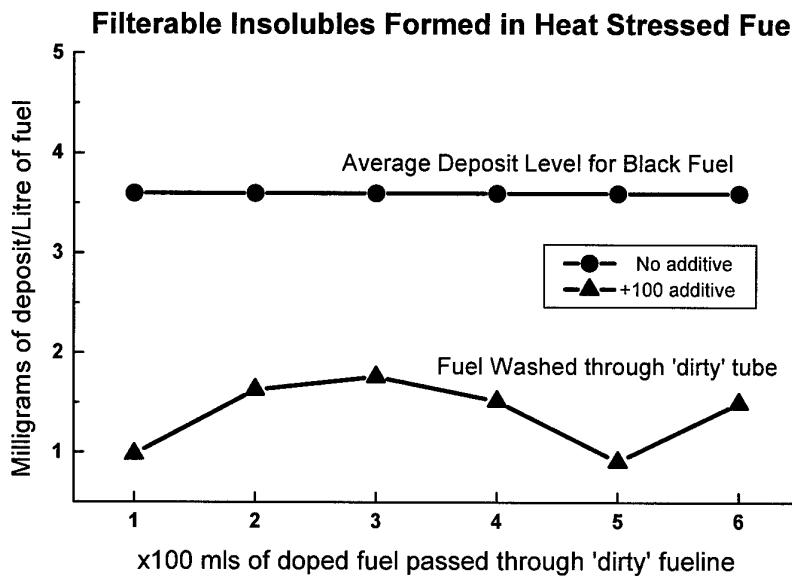


Figure 6. Filterable Insolubles Formed in Heat Stressed Fuel

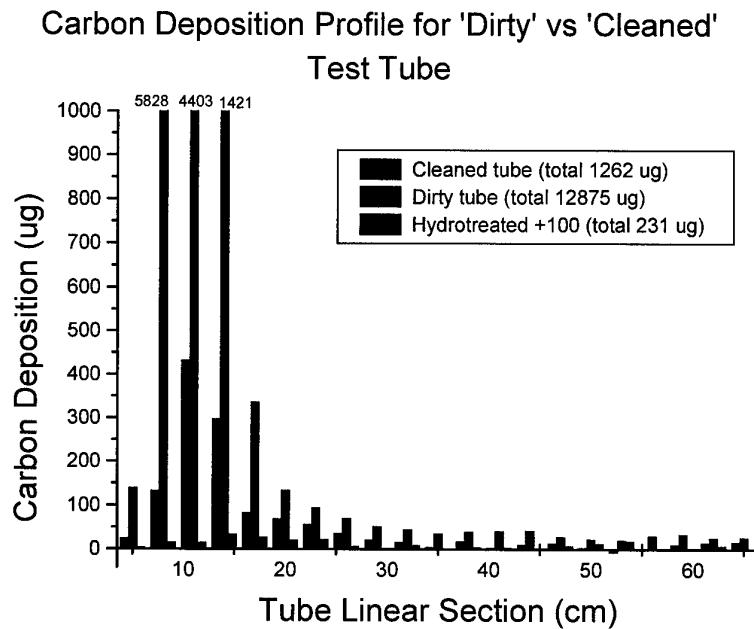


Figure 7. Comparison of deposition in 'dirty' vs 'cleaned' tube.

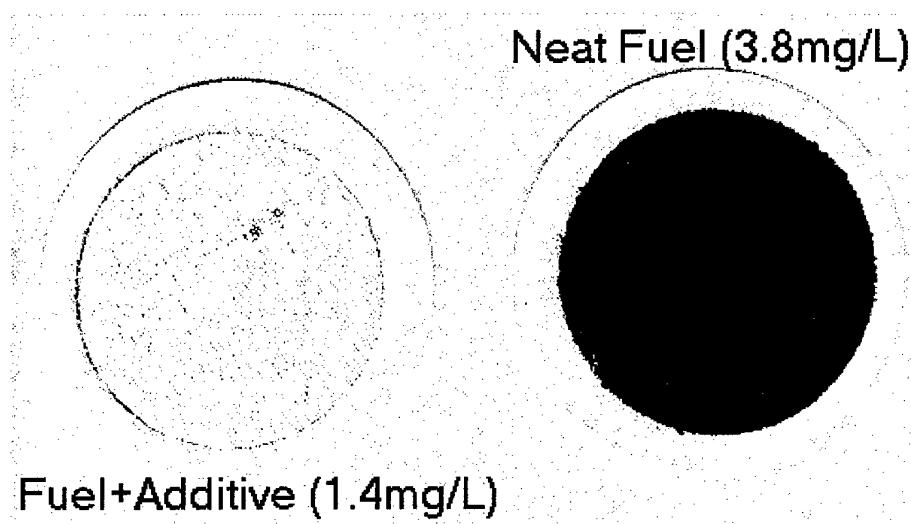


Figure 8. Comparison of Filterable insolubles for Thermally Stressed Black Fuel

## 4. Conclusions

The Betz +100 thermal stability additive has been found to be effective in decreasing the levels of thermal deposit generated under laboratory test conditions over a large cross-section of Australian-manufactured AVTUR samples and over a wide range of fuel stressing temperatures. The additive was also able to clean pre-deposited specimens without producing large, and potentially damaging particles (chunks) of deposit. The additive, as tested in the AED thermal stability rig, has been found to have a definite upper temperature to which it is effective and was found to be detrimental to fuel thermal stability at the stressing temperature of 400°C.

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19. ABSTRACT  An additive package designed to improve thermal stability of jet fuel by 100°F (~38°C), known as the '+100 additive' or more commonly as the USAF-developed JP8+100 thermal stability additive, was evaluated to investigate its efficacy in reduction of thermal deposits formed in aircraft fuel systems. The additive was claimed to reduce deposits generated on fuel-wetted metal surfaces by up to 90%. An AED-designed rig capable of quantitatively evaluating jet fuel thermal stability was used to investigate jet fuels produced by different Australian refineries with various fuel finishing processes. The additive's effect on deposit formation from these fuels was investigated over a range of temperatures and fuel flow conditions giving both total deposit formation data and profiles of carbon and sulphur deposition on heat stressed, fuel-wetted steel tubing. This fuel additive is to be introduced into RAAF aircraft fuel systems that may have substantial levels of existing thermal deposit. An important consideration was thus the additive's ability to clean dirty fuel-wetted surfaces and the possibility of 'clumps' of deposit being washed into the fuel system. Levels of filterable deposit washed from a pre-deposited test section were monitored and the deposit levels were found to fall below levels generated in non-additised fuel. The +100 additive was found to substantially reduce the levels of carbonaceous deposit formed on hot metal fuel-wetted surfaces and performed as claimed in its ability to clean pre-deposited fuel wetted metal surfaces.				